THE PIONEER SPACECRAFT AS A PROBE CARRIER

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DR. WILLIAM DIXON: What I am going to talk about is the use of the Pioneer spacecraft for probe missions to the outer planets. For this purpose, the Pioneer 10 and 11 spacecraft is taken as the baseline.

The first chart (Figure3-32 is a summary chart and was intended to perhaps be somewhat introductory for this talk and the next one. I have talked with Jim Hyde at JPL about it. What I want to do here is pick out the areas of accommodation that a spacecraft has to have, the characteristics it has to have for this type of mission and then select those in which there is a significant contrast in the characteristics of the Pioneer and Mariner approaches.

The principal areas we thought have to do with the weight availability for carrying the probe, certain aspects of the probe-to-bus link communications and on-board navigation, which has been touched on by Lou Friedman just now. And I'll come back to that later.

I think there is one other difference in philosophy which is worth pointing out here. I am talking about the adaptation of a spacecraft design, a spacecraft which has already been designed, built, and flown and, to some extent, completed its flight objectives. Jim is going to be talking about how you would do these missions with a Mariner. I think he will take as a baseline the Mariner-Jupiter-Saturn and apply it to Mariner-Jupiter-Uranus. Those are spacecraft which have not been built and for which the design is not yet committed.

So when I say "What do you have to do to a spacecraft to accommodate a probe," we have to go back and change something that has already been built and he still has the option of incorporating certain things into the design as it proceeds. And this makes a little difference in philosophy.

MARINER AND PIONEER AS PROBE BUSES, AREAS OF CONTRAST

	PIONEER	MARINER
WEIGHT MARGIN AFTER ACCOMMODATION OF PROBE*	(SU) ~ 100 LB (S) ~ 200 LB (J) ~ 1100 LB	(JU) WEIGHT INCREASE HANDLED BY TRIP TIME PENALTY OF ~1 YEAR (SU, S) CANNOT BE DONE (J) ~ 200 LB (DEPENDS ON LAUNCH OPPORTUNITY)
PROBE-BUS LINK COMMUNICATIONS		
HIGH-GAIN (PENCIL BEAM)	DESPUN ANTENNA	FIXED ANTENNA
MEDIUM-GAIN	AXISYMMETRIC FIXED ANTENNA	
ON-BOARD NAVIGATION SENSING (BEYOND GROUND-BASED RADIO)	SPINNING SENSOR HAS GREATER SKY AREA IN SWATH	FIXED SENSOR HAS GREATER SENSITIVITY (DIMMER TARGETS); CAN SEE SATELLITES FROM FARTHER OUT

FIGURE 3-32

* [illegible] CENTAUR [illegible] LAUNCH VEHICLE

On the weight margins - we'll justify these somewhat later - we have looked at the Pioneer for Saturn-Uranus missions. (The underline under the U means Uranus is where the probe goes.) There is roughly a hundred pound margin over what the launch vehicle can carry. We are talking about the same launch vehicle in all cases, the Titan/Centaur/TE 364 launch vehicle.

For a direct mission to Saturn, the spacecraft can be lighter, providing a 200 pound margin.

For a Pioneer to take an atmospheric entry probe to Jupiter, you get an eleven-hundred-pound margin. This is consistent with John Wolfe's discussion this morning that there is enough margin that you can consider an orbiter mission at the same time as a probe mission, in conjunction with it.

The Mariner people first looked at a Jupiter-Uranus mission without a probe. When they put the probe on, there is a certain weight increase and that increase can be accommodated on the launch vehicle, but it comes about by increasing the trip time about one year for every hundred kilograms; and 100 kilograms is roughly what the weight increase is.

I think on the Mariner, using the same launch vehicle, if Saturn is the first stop, I say it cannot be done here, either Saturn-Uranus or Saturn direct mission. Maybe I should qualify that. Most of what we have looked at for Saturn are launches in the late '70's or the early '80's, and that turns out to be about the worst possible time to go to Saturn. If you looked at a different part of the Saturnian year, you might get an improvement and maybe it can be done.

My estimate of the Mariner margin for a Jupiter-only probe is 200 pounds. That would also depend on the launch opportunity somewhat.

In the area of the communications link, we have primarily a different characteristic because Pioneer is a spinning spacecraft

and the Mariner is 3-axis stabilized. As Byron Swenson's pictures showed, communication from the entering probe is to the spacecraft's aft hemisphere. With the rotating Pioneer, the easiest thing to use is an axisymmetric fixed antenna. But you are wasting a lot of your beam. It runs around the whole range of spacecraft centered longitudes or clock angles and so it does not have a very high gain. If you want a higher gain, like a pencil beam, you have to despin the antenna on the Pioneer. But with the Mariner, you can use a more direct or fixed antenna. So there is a potential, say, for equal amounts of mechanical complexity using fixed antennas of about a six or seven dB improvement on the Mariner.

Lou Friedman, talking about navigation, has pointed out that certain of the planetary probe objectives can be handled with radio navigation alone. So this comparison of optical navigation applies in other cases, particularly for probe missions to Uranus and for probe missions to the satellite Titan.

Mariner proposes to use a TV camera or vidicon-like sensor. Being 3-axis stabilized, it has a potential for using a longer exposure and having greater sensitivity. Therefore, it can see dimmer targets, it can see certain satellites from farther out.

For the Pioneer, the sensing we have proposed is the V-slit sensor. It has trouble seeing stars much dimmer than fourth magnitude and, therefore, you have to come closer to see them. Your navigation time might be restricted. One compensating point is that a spinning sensor has a greater sky area in the swath. You can use fixed stars from the entire roll - three degrees by a complete revolution - your guidepost for navigating. However, if you are going down to dimmer targets, there are probably more stars per square degree that you can see, anyway. So I think these are areas of greatest contrast.

With Figure 3-33 we will talk about just the Pioneer. Figure 3-33 is a model very similar to the one that John

MODEL OF PIONEER 10 AND 11

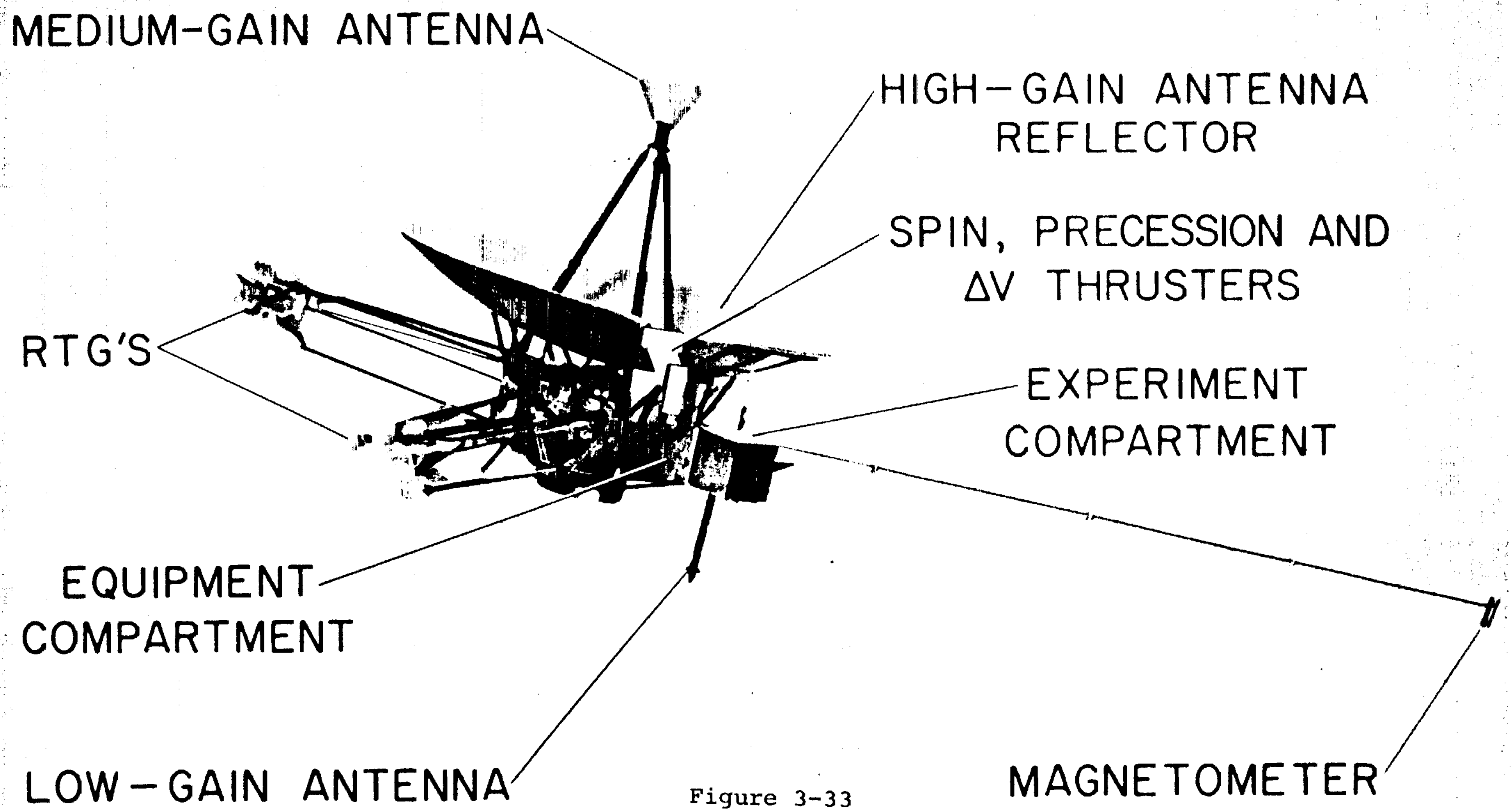

Figure 3-33

Wolfe showed of the Pioneer F&G spacecraft. I am not going to go through it in any detail; I just want you to see what it is like because when we put a probe on we will see how it differs. It is spin stabilized. It has a large dish with an antenna beam along the spin axis. For that reason, we do keep the spin axis pointed toward the Earth, or close to it, during the cruise phase when we are far from the Earth. If you point it significantly far from the Earth, then you do lose downlink communications.

The plane at the bottom is the interface between the spacecraft and the launch vehicle.

Figure 3-34 shows how that region of the spacecraft is used to accommodate a probe. This is looking at the Pioneer from the bottom end. Above the probe adapter which expands out to a 37-inch diameter, is that same interface. The probe adapter matches a standard 37-inch diameter third stage adapter. And the probe, which you will see plenty of other designs of, has a 35-inch diameter which fits within the probe adapter.

This particular version comes from a study of a Saturn-Uranus probe mission, and I might add that it incorporates a number of things that are required because you are going to Saturn and Uranus. In other words, there are differences for the Pioneer if you are going to send it out to Uranus whether you take a probe or not. There are also differences for the Pioneer if you put a probe on it, whether you go out to Uranus or not. So I am going to try to distinguish between those two classes.

Because of the Uranus mission, we do have a star mapper, a navigation device; we have a multi-hundred watt RTG and we have X-band capability.

We have also replaced what was an omni-antenna in the back of the spacecraft by a combination antenna. There is a loop-vee antenna which gives the sort of pattern Byron Swenson indicated was necessary.

PIONEER SATURN URANUS FLIGHT SPACECRAFT

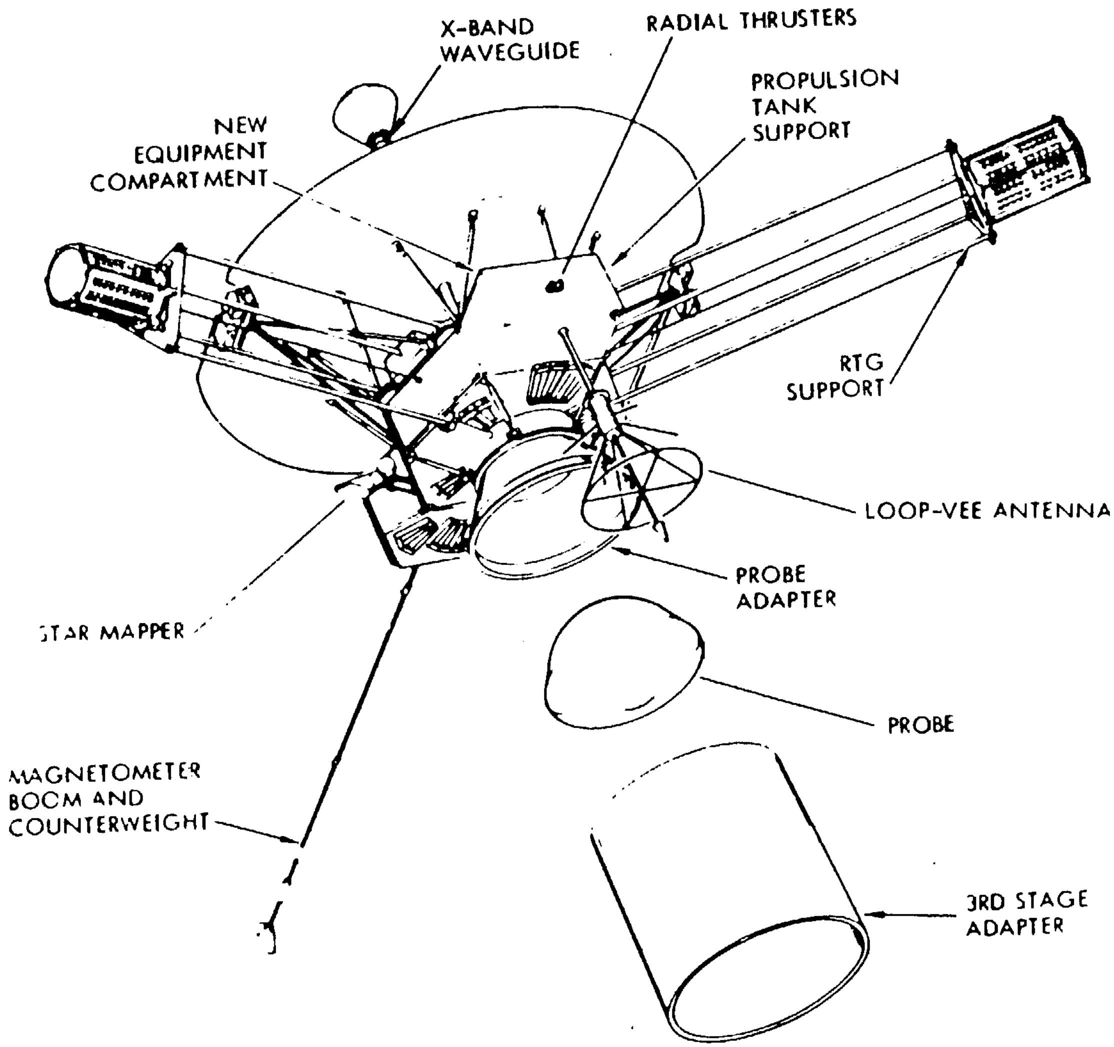

FIGURE 3-34

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OF POOR QUALITY

It is not the full rear hemisphere, but it is a hollow cone-shaped pattern for receiving signals from the probe as it descends. And then we have put the S-band omni-antenna on the end of that.

For this mission and this type of antenna, 400 megaHertz was the link frequency between the probe and the bus. Bus-to-Earth communication is at S-band, around 2300 MHz.

Figure 3-35 shows some details, and probably more than you can see. We have now turned the spacecraft on its side. On the right is the third stage of the launch vehicle. In the center is the probe with the business end toward the right - that is the heatshield end. And it is based on the McDonnell probe concept of which you saw a model this morning. The Pioneer equipment compartment is to the left and the dish would be out of the picture to the left. The newly added conical section is seen to the left of the probe. The probe itself is held at three points by bolts which can take all of the launch loads and can be separated by ordnance to release the probe to the right.

There is a modification in the adapter so that you only need one separation. You separate the launch vehicle from the spacecraft at this point "B". Then, when the probe goes, there is no other separation that has to be made.

Figure 3-36 shows the weight of Pioneer missions. In Column 1 we have the weight of Pioneer G (or Pioneer 11) as launched. Of course, it didn't carry a probe so it has 442 pounds of spacecraft not counting propellant or instruments; 67 pounds of instruments; 59 pounds of usable propellants, for a total weight of 568 pounds. The adapter was about 30, and there was not a lot of margin. That is about what the Atlas Centaur TE 364 could send to Jupiter.

When you put a probe on, you have to go to the Titan launch vehicle if you are going to Jupiter or beyond. So these other three cases show it with a Titan.

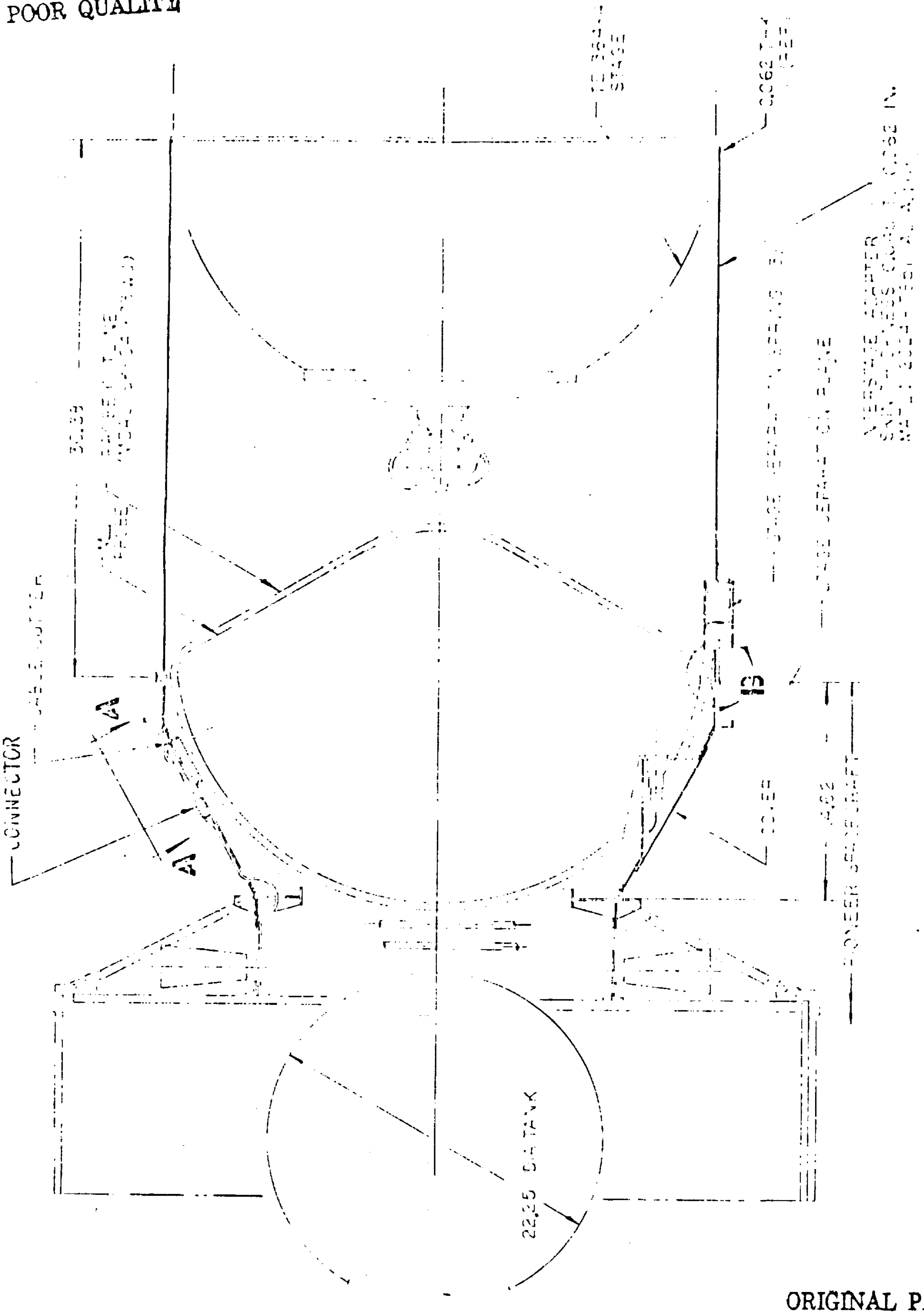

FIGURE 3-35
BUS PROBE INTERFACE LAYOUT

SPACECRAFT WEIGHT

	PIONEER SPACECRAFT/MISSION							
	G (11)		SATURN PROBE		SATURN/ URANUS PROBE		JUPITER PROBE	
	KG	LB	KG	LB	KG	LB	KG	LB
SPACECRAFT (EXCLUDING USABLE PROPELLANT, INSTRUMENTS, PROBE)	200.7	442.5	240.3	529.8	280.3	617.9	245	540
INSTRUMENTS	30.4	67.0	27.9	61.5	27.9	61.5	32	70
USABLE PROPELLANT	26.9	59.2	34.8	76.7	50.4	111.2	41	90
PROBE	-	-	113.4	250	113.4	250	154	340
SPACECRAFT WEIGHT AT LAUNCH	258.0	568.7	416.4	918.0	472.0	1040.6	472	1040
ADAPTER	13.6	30.0	27.0	59.5	27.0	59.5	27	60
GROSS WEIGHT	271.6	598.7	443.4	977.5	499.0	1100.1	499	1100
INJECTION ENERGY REQUIRED* (APPROXIMATE)	93		140		140		100	
LAUNCH VEHICLE**	A		T		T		T	
LAUNCH CAPABILITY	277	610	549	1210	549	1210	998	2200
WEIGHT MARGIN	5	12	106	232	50	110	499	1100

*KM^2/SEC^2

**A = ATLAS/CENTAUR/TE-364-4; T = TITAN/CENTAUR/TE-364-4

FIGURE 3-36

What we did in a study a year ago was a spacecraft that could take a probe to either Saturn or Uranus or both, according to the old plan. That probe was deemed to weigh 250 pounds, although we understand there is a significant margin within that. The spacecraft's dry weight increased about 170 pounds for a number of reasons, and the propellant weight also went up quite a bit to handle all of the maneuvers we are talking about. The bus experiment payload for that mission was a selected payload which was 61 pounds, so the whole thing came out 1040 pounds, or eleven hundred with an adapter. And with the adapter, with a nominal C_3 of 140, the approximate launch capability is around twelve hundred pounds. So that was 100 pounds of margin. (Column 3).

If you make it only a Saturn probe (Column 2) - as we will see in a moment - there are a number of provisions required for Uranus that don't have to be put on; and it would be considerably lighter.

Looking at the Jupiter probe (Column 4), the first indications are that the probe itself, needing a significantly heavier heatshield, would weigh about 340 pounds compared to 250. But the spacecraft, again, would reflect more the Saturn than the Uranus requirements; they would not be so heavy, science just nominally selected, propulsion just a little more than Saturn because you have a somewhat larger deflection at Jupiter. And this is where the eleven hundred pound margin comes. To Jupiter, 100 km^2/sec^2 is typical launch energy.

I might add that these are approximate. They depend a lot on just what launch year and what launch window and other definitions you need are.

Figure 3-37 summarizes the requirements and the impact on the bus to carry a probe. Suppose we start with Pioneer F&G, which is basically a Jupiter mission. We add a probe - I am still talking about a Jupiter mission, and we will look later at what it takes

INFLUENCE OF PROBE ON BUS DESIGN

ITEM	REQUIREMENT	IMPACT
PROBE WEIGHT	SUPPORT STRUCTURE: INTERFACE AREA	ROUTINE
	MASS PROPERTIES CONTROL: DEPLOYMENT COUNTERWEIGHT	MODERATE
THERMAL CONTROL (PROBE)	PROVIDE -20°F TO +32°F ENVIRONMENT	ROUTINE
THERMAL CONTROL (BUS)	ANALYZE EFFECT OF PROBE POSITION	MINIMAL
PROBE-RELATED MECHANISMS AT SEPARATION	NEW MECHANISMS AND ORDNANCE; EXTEND ORDNANCE-FIRING CIRCUITRY AND COMMANDS	MODEST
ELECTRICAL POWER	PROBE THERMAL (≤4 W STEADY) CHECKOUT AND BATTERY CHARGE (DUTY CYCLE BUS INSTRUMENTS) SEPARATION ORDNANCE (TRANSIENT: CAPACITOR DISCHARGE)	NO IMPACT ON RTG COMPLEMENT
PROBE TELEMETRY (PROBE-BUS RELAY)	LINK ANTENNA ON BUS	MODEST
	RECEIVER-BIT SYNCHRONIZER } PROBE DATA BUFFER } ON BUS	ROUTINE
	DATA STORAGE CAPACITY INCREASE (BACKUP MODE)	MODEST
	DATA HANDLING (88 BITS/SEC)	NONE
	RF HARDLINE FOR CHECKOUT BEFORE SEPARATION	ROUTINE

FIGURE 3-37

to extend that out to farther planets. You have the weight of the probe, and we have already demonstrated that that is within the capability of the launch vehicle. As far as the bus is concerned, you need a support structure, an interface area which I have described, and those are routine structural modifications. Mass properties control: on a spin-stabilized spacecraft we have to exert specific control over the principal axis to keep it coincident with the antenna axis, so there are some moderate things we do there, including a counterweight to accommodate the probe weight beneath the spacecraft.

Thermal control of the probe: this was the general requirement, primarily catering to the battery aboard the probe. Although it was permissible to deviate from that early in the mission, that was felt to be a routine thermal control requirement on the spacecraft and not requiring much power. We also have to worry about the thermal control of the bus. Putting the probe in this region of the spacecraft does block the radiation path through the louvres a little bit. We feel that the physical impact is minimal but the analysis is something that has to be done.

There are mechanisms that have to be added so that at separation we can do things like cut cable, fire squibs on the probe, and fire these ordnance activated bolts that actually separate the probe. We feel that is a modest requirement. We have circuitry on the Pioneer now that fires ordnance. The chief difference is that is normally done soon after launch. For this mission, it would be done close to the end of the mission and so it would take additional analysis and tests to verify that the circuitry meets the lifetime requirements.

Electrical power is interesting; really no impact on the RTG complement. The reason is that the probe thermal requirements are very small, less than four watts steady power. The check out and battery charge are things that you can do by duty cycling. This would be done only at isolated times during the

mission. The battery would probably be charged just once before probe separation; and for those purposes, you could turn off the instruments on the bus without really harming their mission and use that power. So the presence of the probe does not really aggrevate your RTG requirements at all.

The probe telemetry, using the probe-to-bus relay has a number of requirements. Besides the link antenna on the bus, we need a receiver, bit synchronizer, a probe data buffer. (The probe data comes from one clock and the data is handled on the spacecraft from another clock. And, because, of course, they are opposite ends of the link, they are not synchronized, so you need a small buffer.) Data storage capacity increase: We regard a primary mode as relaying probe data to Earth in real time. The backup mode is to store it on the spacecraft for later transmission. This is in case, for example, of a ground station being down at that instant; you wouldn't want to lose all of the probe data. In our studies the probe would transmit data at an information rate of 44 bits per second, but it is coded two-to-one so it is actually sending 88 symbols per second. The spacecraft would not decode it, so it would have to continue to handle 88 bits per second in its downlink transmission. But that is not a problem. You will see that in a moment on another chart.

Also, for check out of the probe while it is still attached to the bus, there is an RF hardline which would use the same channels on both the probe and the spacecraft, except it would bypass the antennas.

One other requirement which I didn't list here and has been mentioned is the requirement for propulsion capability. We feel the Pioneer is sort of naturally suited for three things: it provides the probe with trajectory control, orientation control, and spin rate control. And these are things it does using the propulsion system essentially as it stands, except, as I have noted, you would have to have greater propellant capability to handle the bus deflection maneuver after separation.

I think the trajectory control is exemplified by Pioneer 10 through its trajectory control or propulsive control achieving an occultation by Io, one of these little satellites far away whose position is not known too well and it is not too big. But I think the fact that this occultation was attained shows that the Pioneer spacecraft, with its propulsion system and radio navigation alone can hit targets the size of a Galilean satellite. That is really the point involved here.

Secondly, the orientation control; Byron Swenson observed it was a constraint that the spacecraft remain Earth pointing at all times. Actually, I don't think that is quite a concrete constraint. It is an operational constraint. The spacecraft has the capability of being directed to point away from the Earth and do something and come back to the Earth, even if that interim attitude takes away your downlink communication. In fact, Pioneer 10 was pointed away from Earth line after the Jupiter encounter. The encounter was last December and this maneuver was around February. It was pointed away and it was out of communication with Earth for a couple of weeks. So it is strictly an operational constraint and not a physical limitation.

On the other hand, I think the mission analyses that have been presented show that releasing the probe in an Earth line attitude is a natural way to control its attitude and still achieve very small angles of attack upon entry. That is, generally speaking, the trajectories that come around each planet in a counter-clockwise manner, approaching with a relatively low angle of attack are those in which the entry trajectory is approximately parallel to the Earth line so that this constraint is not a harmful one.

Figure 3-38 shows what carrying the probe requires of the bus, and I was doing that generally thinking in terms of a Jupiter mission, because that is what the Pioneer F&G does.

Figure 3-38 shows what happens if you make the target planet Saturn or Uranus. Mission duration increases, as shown.

FIGURE 3-38

INFLUENCE OF TARGET PLANET SELECTION ON BUS DESIGN

ITEM	TARGET PLANET		
	JUPITER	SATURN	URANUS
MISSION DURATION (YEAR)	1.4	3.4	6.9
COMMUNICATIONS (BITS/SEC)			
PIONEER 10/11, 8 W S-BAND	1024 (OK)	256 (OK)	32 (INADEQUATE)
8 W X-BAND	≥2048	≥2048	512 OR 1024 (OK)
NAVIGATION	RADIO (OK)	RADIO (OK)	RADIO (DOUBTFUL)
POWER (WATTS)			
PIONEER 10/11 4 SNAP-19	144-150 (OK)	125-134 (OK)	88-102 (INADEQUATE)
2 SNAP-19 (HPG) OR 2 MHW			190 (OK)
SUMMARY	PIONEER F/G IS OK	PIONEER F/G IS OK	• POSSIBLE SELECTIVE REDUNDANCY AUGMENTATION • ADD X-BAND COMMUNICATIONS • ON-BOARD OPTICAL NAVIGATION SENSOR IS DESIRABLE • INCREASE RTG POWER SOURCE CAPACITY

In communications, the Pioneer system's eight watts at S-Band, gave us 1024 bits/second from Jupiter, which is okay for this mission. We would project 256 bits/second at Saturn, and that is still satisfactory for the probe mission. Thirty-two bits/second is all you would get at Uranus, so that is inadequate.

The point here is that to go to Uranus, you have to improve the communications; that is, to conduct a probe mission at Uranus. We propose incorporating X-Band, which would get you plenty in terms of bit rate.

Navigation, I think this has already been discussed. Radio is doubtful, and we would propose an on-board optical navigation sensor at Uranus; and also for Titan, which I haven't listed explicitly here.

In terms of power, if we take the Pioneer 10-11 experience, we would measure at Jupiter arrival about 144 to 150 watts. At Saturn, somewhat less. But the spacecraft budget is only about 105 watts with everything turned on, so this is okay and gives you margin to add things for the probe, which only needs a few watts.

Projecting it out this long (to Uranus), the power is not expected to be adequate for a probe mission so we would also talk about increasing RTG power source capacity.

In conclusion, I have separated the requirements on the bus in what you would do to carry a probe; and also looked at what you would do to move the target planet beyond Jupiter. The Pioneer 10 and 11 design, adapter to carry the probe, is adequate for Jupiter and Saturn. For a Uranus probe mission, additional spacecraft modifications are necessary, as shown.